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An REU/RET Project: IoT Platform and Network Data Visualization

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Andre Latte Dean Jr. is a senior undergraduate student studying Electrical Engineering at Morgan State University. In 2016, Andre joined the Morgan State family and has gained knowledge from many of the resources that Engineering has to offer. in the summer of 2019, he was selected as an intern by the Exelon Corporation and acquired experience under the smart metering and technology team. This opportunity introduced him to IoT devices – which became the inspiration to pursue his research in IoT devices with the National Science Foundation in the summer of 2021. Andre is looking forward to his graduation in 2022 and is interested in pursuing his masters degree in Electrical Engineering.

An REU/RET Project: IoT Platform and Network Data Visualization

Abstract

Internet of Things (IoT) is a connected network of devices that exchange data using different protocols. The application of IoT ranges from smart Televisions and intelligent refrigerators to smart Transportation. This research aims to provide students with hands-on training on developing an IoT platform that supports device management, connectivity, and data management. People tend to build interconnected devices without having a basic understanding of how the IoT platform backend functions. Studying the Arm Pelion will help to understand how IoT devices operate under the hood.

This past summer, Morgan State University has hosted undergraduate engineering students and a high school STEM teacher to conduct IoT security research in the Cybersecurity Assurance & Policy (CAP) Center. The research project involved integrating various hardware sensor devices and real-time data monitoring using the Arm Pelion IoT development platform. Some of the student/teacher outcomes from the project include: 1) Learning about IoT Technology and security; 2) Programming an embedded system using Arm Mbed development board and IDE; 3) Developing a network of connected IoT devices using different protocols such as LWM2M, MQTT, CoAP; 4) Investigating the cybersecurity risks associated with the platform; and 5) Using data analysis and visualization to understand the network data and packet flow.

First, the student/teacher must consider the IoT framework to understand how to address the security. The IoT framework describes the essential functions of an IoT network, breaking it down into separate layers. These layers include an application layer, middleware layer, and connectivity layer. The application layer allows the users to access the platform via a smartphone or any other dashboard. The Middleware layer represents the backend system that provides edge devices with data management, messaging, application services, and authentication. Finally, the connectivity layer includes devices that connect the user to the network, including Bluetooth or Wi-Fi. The platform consists of several commercial IoT devices such as an intelligent camera, baby monitor, and other devices. We then create algorithms to classify the network data flow; to visualize the packet flow in the network and the structure of the packet data frame over time.

Keywords: IoT Education, Cybersecurity concepts, Internet of Things, Arm Pelion platform, Team collaboration, Engineering Education.

Introduction and Motivation

This past summer, Morgan State University hosted two undergraduate engineering students and a high school STEM teacher and conducted IoT security research in the Cybersecurity Assurance & Policy (CAP) Center in partnership with the Smart Cities REU/RET program. The program aims to teach students team building and leadership skills while working on an assigned research project. By the end of the program the teacher was able to design hands-on activities for high school junior and senior level engineering courses. Additionally, graduate mentors oversaw the progress of each student in the team. The target area for this research was the Internet of Things.

The Internet of Things (IoT) is a connected network of devices that exchange data for helping facilitate our daily life activities. IoT applications range from intelligent cameras and to smart cars. Many households worldwide use these smart devices [1,2], including multiple applications and Bluetooth connectivity for control and management. These devices contribute to the realm of the IoT and create a smart home ecosystem that can be monitored and managed using a single application or device [3, 23]. While this intelligent home ecosystem aids in the efficiency of everyday life, the security risks involved in implementing these IoT devices are still under investigation [24]. Authors in [4] examined the security vulnerabilities of IoT devices present in consumers' homes in an experimental environment.

Furthermore, most IoT devices present cybersecurity risk(s) associated with the devices affecting several IoT platforms in the market. In this work, students focused on the Arm Pelion IoT platform throughout this research because it offers comprehensive and accessible online documentation for beginners. Students used the Nucleo-64 STM32L476 board, compatible with Arm Pelion, to perform the experimental setup. The network setup consists of building an IoT platform that supports the device, data management, and connectivity. Building a platform of connected IoT devices will allow the students to understand its operational mode and functionalities. The generic architecture of an IoT platform has three layers: the application layer, the middleware layer, and the connectivity layer. The application layer provides interaction with end-users using a dashboard. The middleware layer handles are the software backend system that handles data management, messaging, and authentication services. The connectivity layer includes devices that connect to the user’s network, including Bluetooth or Wi-Fi.

The primary scope of this research is to help students prepare for successful careers by teaching them the core concepts of cybersecurity and Internet of Things education. Secondly, students learn how to collaborate and work efficiently in a team. Lastly, students also developed critical thinking and practical skills throughout the project. The objectives of this research are as follows.

1- To explore the theoretical and practical concepts of the Internet of Things.
2- To learn about the security vulnerabilities of IoT devices using the Arm Pelion platform.
3- To engage high school students and teachers in conducting real-world engineering research and problem-solving.
4- To teach students how to program embedded systems using the Nucleo board.
5- To provide students the opportunity to work and collaborate on real-world security problems.

Problem Statement

While the demand for engineering jobs is rising, many students face critical issues during the recruitment process due to their lack of hands-on skills after college or university [20]. Some courses available at the university or college level do not necessarily provide students with labs that could facilitate gaining hands-on knowledge, on top of the theory learned from the classroom, to make them more competitive with their peers [17]. Students will become critical thinkers in this project by identifying a real-world problem faced in the IoT ecosystems. Although they might realize that various IoT devices are being adopted in households worldwide, they must also understand that the security of IoT devices has become a significant concern for consumers. The proliferation of IoT platforms in the market allows hackers to create new ways to infiltrate the user's system [22]. Hackers are now exploiting the vulnerabilities on edge devices and gateways from the IoT platforms to gain authorized access to systems leading to attacks and loss of private information.

Purpose and Significance of the Work

The primary objective of this project is to engage students with research at an early stage in their college matriculation process. We realized that students were more likely to commit to work during the summer than the regular Fall and Spring semesters. Hence the idea of bringing them up to speed during the summer. Some of the Cybersecurity skills required by giant companies during the recruitment process include communications skills, writing skills, knowledge of Cybersecurity concepts and issues, security vulnerabilities, basics of C/C++, and python programming. Throughout this project, we expose students to the real-world problem faced by the biggest high-tech companies like Google, Amazon, IBM, Cisco, Facebook, Microsoft, and others. Second, some of the learning expectations include the following:

- Working in teams
- Managing deadlines
- Following work schedules
- Becoming critical thinkers and problem solvers
- Learning the fundamental of programming basics hardware devices like the Nucleo-L476RG
- Learning various components of hardware systems
- Building a small network of Internet of Things devices
- Learning how to present a project and provide updates to the team
- Learning how to write and communicate their ideas effectively

Related Work

Internet of Things education is a topic of study that aims to equip students with the knowledge and skills to comprehend hardware and software principles and best practices [18]. Prior study has revealed that students often get dissatisfied with engineering courses due to a lack of practical skills and their professors' high expectations [20].

Students surveyed commercial and open-source platforms such as Google Cloud, Microsoft Azure, Amazon Web Services (AWS), Cisco IoT Cloud. They found that no study has been done on home applications using the Arm Pelion Platform.

In [3], Pandikumar et al. presented a solution that includes a user interface for the smart home using the Global System for Mobile (GSM) communications. The GSM-based wireless communication system serves as a webserver in the smart home. The interface converts users' inputs into GSM Short Message Service commands parsed and executed by a microcontroller to control smart home appliances and lighting.

Karim et al. in [4] proposed a lightweight IoT middleware for secure deployment of IoT applications to provide security resources for organizations and individuals using the REST API (Representational State Transfer - Application Programming Interface) interface. Each API endpoint would be secured using Access Control List (ACL). The middleware uses RESTful services and enables the developers to create and modify their resources according to applications needs.

Garg et al. [15] introduced a secure IoT system that does not allow attackers to infiltrate the network via IoT devices and secure data in transit from IoT devices to the cloud. Representational State Transfer (REST) API allows the end-users to connect devices to applications securely. In the model proposed in the paper, the middleware exposed the device data through REST and acted as an interface for the user to interact with sensor data.

Table 1: Related Work and Gaps

Title	Authors	Contributions	Gaps
Internet of Things Based Architecture of Web and Smart Home Interface Using GSM [1]	S. Pandikumar, R.S. Vetrivel	This paper presents an IoT and GSM-based design of intelligent home control systems. The data is gathered and transmitted using GSM-SMS.	The average SMS delivery time was 3.5 sec, which is slower than other IoT platforms. The research did not include data transmission and authentication processes.
Lightweight IoT middleware for rapid application development [2]	Karim, I, Rozeha, R, Hadi, F, Adib, S, & Mohammad, B.	The authors presented a lightweight IoT middleware for rapid development and deployment of an IoT application using the REST API (Application programming interface) interface. Each API endpoint would be secured using Access Control List (ACL).	Security risks challenges were not addressed, including the mitigation approach.
Security IoT Devices and Securely Connecting the Dots Using REST API and Middleware [15]	Hittu Garg and Mayank Dave	IoT device security, IoT secure communication, IoT threats	The research did not provide a straightforward solution to prevent any data breaches and leakage at the middleware.

Research Methodology

The research study was divided into two teams: undergraduate students, participating in the Research Experience for Undergraduates (REU) program, and teacher, participating in the Research Experience for Teachers (RET) program. Both teams collaborated remotely and received IoT devices and the Nucleo board at their respective addresses. Figure 1 shows the collaboration between the REU participants and the RET participant

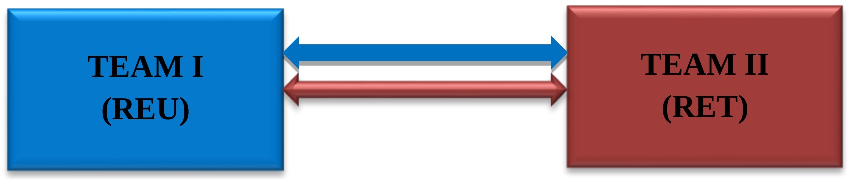


Figure 1: Workflow between TEAM I and TEAM II

Students, Faculty, Mentors, and Teacher Collaboration

The participation involved two undergraduate students and a teacher from Baltimore City High School working with graduate mentors. The graduate mentors work under the supervision of a faculty member who oversees the whole project. For TEAM 1, we had one undergraduate student from Morgan State University and one from Alabama A&M University. For TEAM II, we had a teacher from Baltimore City Public high school.
Mentors spent the first two weeks engaging students on how to conduct research and the fundamental of programming. The mentors then provided the faculty advisor with progress updates.

Table 2 shows the rules, contributions, and evaluation criteria of the team.

Table 2: Team Rules, Contributions and Evaluation Criteria

Position	Different Rules	Contributions	Evaluation Criteria
Faculty	Project coordinator and supervisor.	-Provide ideas to develop the objectives of the project. -Provide valuable feedback to the team. -Main graduate mentor faculty advisor. -Provide a space/lab to experiment.	Not Applicable (N/A)
Graduate Mentors (Ph.D. Students)	Project Mentors	-Collaborate directly with students. -Monitor the students' progress by scheduling a one-hour meeting from Monday to Friday. -Teaching basic engineering concepts to students. -Provide students with adequate resources, including relevant engineering papers, to understand the project. -Teach students how to program embedded systems. - Create a productive environment and facilitate collaboration among students and a teacher. - Facilitate the assessment and accomplishment of the project.	Check to see if students successfully met all the project requirements and mastered teamwork skills and hands-on experience.
Undergraduate students (REU) majoring in Electrical and Computer Engineering	REU Students	-Build a network of Internet of Things devices -Work on the literature review to understand the state-of-the-art problem in cybersecurity, present to team -Provide daily updates -Explore the Nucleo board in-depth to understand the functionalities -Follow the schedule -Support the whole team by assisting REU teammate and RET student	Successful completion of the project at the end along with the final report
Teacher (RET)	RET Student	-Build a network of Internet of Things	Successful

Baltimore City Public High School	*(Teacher)**	devices -Work on the literature review to understand the state-of-the-art problem in cybersecurity, present to team -Provide a daily update. -Explore the Nucleo board in-depth to understand the functionalities. -Task to read at least one literature paper and present it to the team. -Follow the schedule -Support the whole team by assisting REU students -Provide extra updates for the design of the course for junior and senior level high school students.	competition of the project at the end and the final report and course design as indicated in the **Appendix** section.

Weekly Schedule and Activities

Table 3: Weekly Milestones for RET and REU participants

Weekly Schedule	Tasks and Descriptions	Assigned to	Deliverables
Week 1 (06/21 – 06/28)	-Virtual meeting with the two undergraduate students' participants and the teacher for self-introduction -Basic discussion about student's prior courses taken in the department - Basic discussion to learn about the teacher expectation at the end of the research	Students and Teacher Students Teacher	Students and a teacher provide an individual report
Week 2 (06/28 – 07/05)	-Review academic papers targeting Internet of Things education -Understand the Nucleo board components		-Students and a teacher provide individual weekly report -Group presentation
Week 3 (07/05 – 07/12)	-Introduction to IoT Arm Pelion Platform -Learn how to write a simple program	Students and Teacher	-Students and a teacher provide individual weekly report -Group Presentation
Week 4 (07/12 – 07/19)	-Design a conceptual diagram for the smart home ecosystem -Explore each component within the smart home	Students Teacher	-Student presentation -Teacher presentation
Week 5 (07/19 – 07/26)	-Data collection from the smart Internet of Things devices -Data visualization using Jupyter software and analysis	Teacher Students	-Teacher presentation -Student presentation
Week 6 (07/26 – 07/30)	-Final report integrate all the skills and experience learned from the project -Final report including a new course design on Introduction to Microcontrollers and Microprocessors for Engineering Education	Students Teacher	Joined Final presentation where students present their session and teacher the course design session in a single PowerPoint

Designing a Conceptual Diagram for Smart Home Ecosystem

The smart home ecosystem consists of multiple IoT devices set up to establish a network testbed. The devices range from the Smart LED light bulb and TV to the Nucleo board. The Arm Pelion platform allows users to upload firmware directly to the board with the online compiler. Several programs can be created from scratch and imported onto the board to meet specific functions and give relevant data. For the research direction, students were encouraged to use Wireshark to capture the network data.

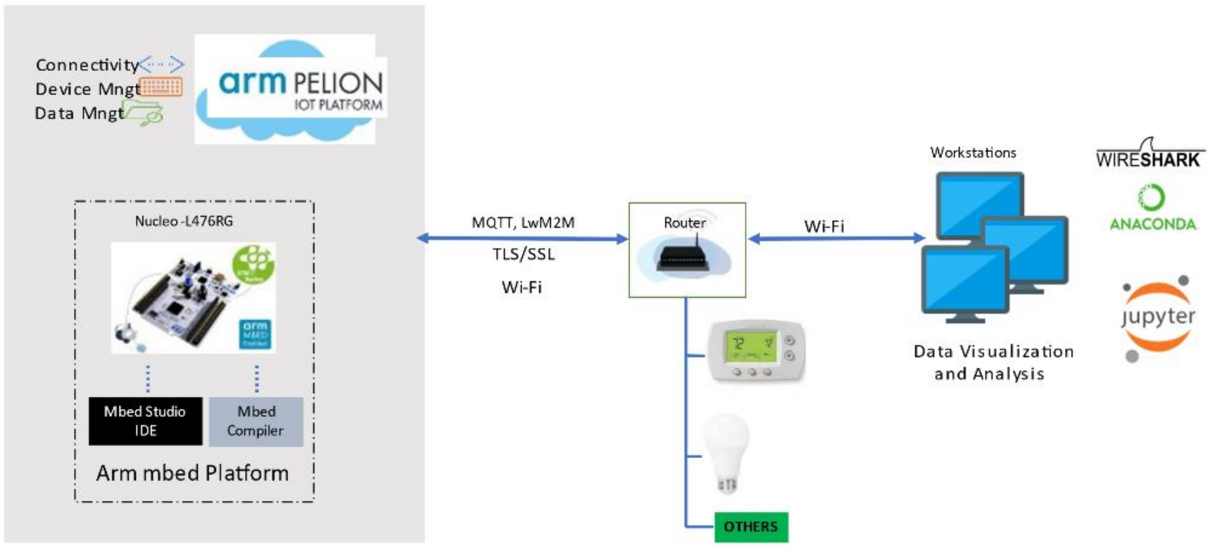


Figure 2: Students Successfully design the IoT Smart Home with Arm Pelion

This project brings various hardware sensor devices and real-time data to build a monitoring application using the Arm Pelion Platform that will support the following:

- Device management
- Connectivity
- Data management

In Figure 2, students successfully designed a Smart Home platform (IoT Application) Using Arm Mbed development board (Nucleo L476RG) and Mbed Studio IDE.

- Mbed Studio is a free IDE for Mbed compatible devices - provides middleware workspace
- Nucleo L476RG Board is the IoT used to communicate with Mbed Studio
- Students learned about different communication protocols such as the Lightweight Machine to Machine (LWM2M) protocol for a low memory device, the Message Queuing Telemetry Transport (MQTT), the Constrained Application Protocol (CoAP), the Wi-Fi protocol for connectivity, the Transport Layer Security (TLS), the Secure Sockets Layer (SSL) protocol for security.
- The router provides Wi-Fi connectivity.
- The workstations hosted different software like Anaconda and Jupyter for data visualization.

Home devices that will be monitored are.

- Smart Thermostat
- Smart LED bulb
- Others

Exploration of the NUCLEO L476RG Board

The Nucleo L476RG, in figure 3, is used to interact with the Arm Pelion platform. Students identified all the components on the Nucleo L476RG, which consists of several bus interfaces such as a Universal Asynchronous Receiver and Transmitter (UART), a Universal Serial Bus (USB), and a Serial Peripheral Interface (SPI).

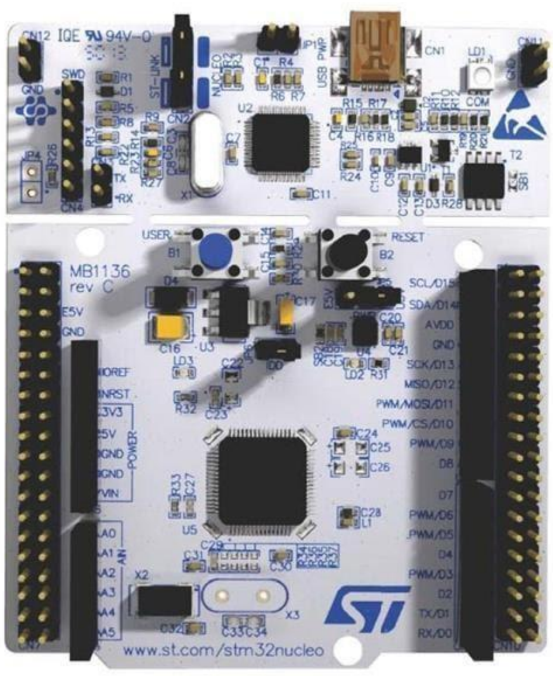
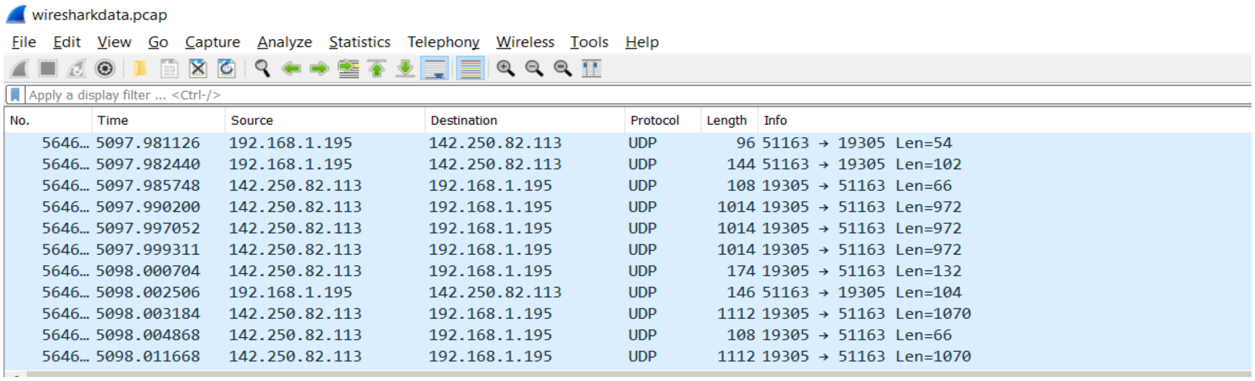


Figure 3: Nucleo L476RG Board

IoT Device Data Collection

After finishing the conceptual diagram, students collected one million real-time data packets from IoT devices, including the intelligent IP camera, the smart thermostat, smart TV, and others using Wireshark on their personal computers. The data was captured in a Packet Capture (PCAP) format, then converted to Comma-Separated Values (CSV) to facilitate the analysis process.



wiresharkdata.pcap

File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help

Apply a display filter ... <Ctrl-/>

No.	Time	Source	Destination	Protocol	Length	Info
5646…	5097.981126	192.168.1.195	142.250.82.113	UDP	96	51163 → 19305 Len=54
5646…	5097.982440	192.168.1.195	142.250.82.113	UDP	144	51163 → 19305 Len=102
5646…	5097.985748	142.250.82.113	192.168.1.195	UDP	108	19305 → 51163 Len=66
5646…	5097.990200	142.250.82.113	192.168.1.195	UDP	1014	19305 → 51163 Len=972
5646…	5097.997052	142.250.82.113	192.168.1.195	UDP	1014	19305 → 51163 Len=972
5646…	5097.999311	142.250.82.113	192.168.1.195	UDP	1014	19305 → 51163 Len=972
5646…	5098.000704	142.250.82.113	192.168.1.195	UDP	174	19305 → 51163 Len=132
5646…	5098.002506	192.168.1.195	142.250.82.113	UDP	146	51163 → 19305 Len=104
5646…	5098.003184	142.250.82.113	192.168.1.195	UDP	1112	19305 → 51163 Len=1070
5646…	5098.004868	142.250.82.113	192.168.1.195	UDP	108	19305 → 51163 Len=66
5646…	5098.011668	142.250.82.113	192.168.1.195	UDP	1112	19305 → 51163 Len=1070

Figure 4: Screenshot of the Data Collected from the Internet of Things Devices using Wireshark software.

The data collection process also helps students understand how industries collect and manage data for analytics and decision-making purposes.
The data was converted into CSV format using Wireshark software, as shown in Figure 5.

	No.	Time	Source	Destination	Protocol	Length	Info
0	1	0.000000	192.168.1.195	142.250.80.42	UDP	75	58088 > 443 Len=33
1	2	0.020993	142.250.80.42	192.168.1.195	UDP	93	443 > 58088 Len=25
2	3	0.108749	192.168.1.195	142.250.81.206	UDP	75	54520 > 443 Len=33
3	4	0.132690	142.250.81.206	192.168.1.195	UDP	93	443 > 54520 Len=25
4	5	0.216415	192.168.1.195	142.250.80.42	UDP	75	59761 > 443 Len=33

```
dataset.shape
```

```
(1007669, 7)
```

Figure 5: Data Collection in CSV format (One Million Data Collected from the IoT Devices). The first number (1007669) represents the number of rows, and 7 represents the number of features.

Description of the Arm Mbed Free Online Compiler

Arm Mbed is a free online compiler for application development for the IoT Arm Pelion. Students learned how to write programs to connect the devices to the platform. The online compiler is accessible via https://os.mbed.com/accounts/login/. The platform offers basic tutorials that help to teach students that unfamiliar with program hardware. Our students found the compiler very easy and flexible to use and familiarize themselves with the platform in less than a week. Arm Pelion provides free documentation making the learning environment appropriate for any entry-level individual.

Expected Results and Importance in Engineering Education

Many universities and colleges partner with giant tech companies to provide network services and monitor the hardware and software devices used within their respective campus. It is vital to understand how the devices within any organization function to protect the privacy of potential users. Training students on building a platform for network data visualization could help them identify any threat orchestrated by a third party, or in other words, an attacker. IoT devices are everywhere, but often students do not understand their primary functions and the impacts of inappropriate usage [19]. This project provides an overview of embedded systems and introduces students to data visualization, critical to understanding IoT devices.

For their results, students installed the Jupyter notebook software on their laptops and manipulated the data collected from the IoT devices to visualize the network traffic flow. Data visualization allows cloud providers (industry) and users to understand the patterns of data generated from the Internet of Things devices leading to important decisions about how to improve the efficiency and effectiveness of the platform. Figures 6, 7, 8, and 9 show the visualization of the data flow based on the protocols, the packets length, and the structure of the packets over time.

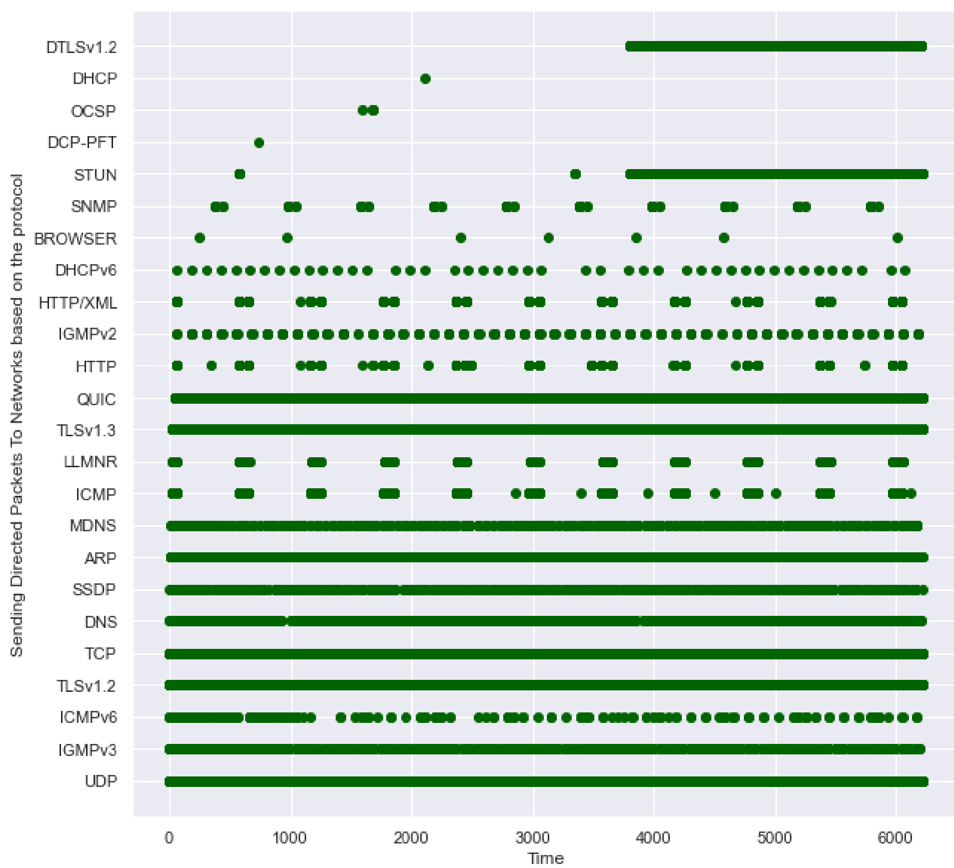


Figure 6: Visualization of the Network Data Flow Based on Protocols

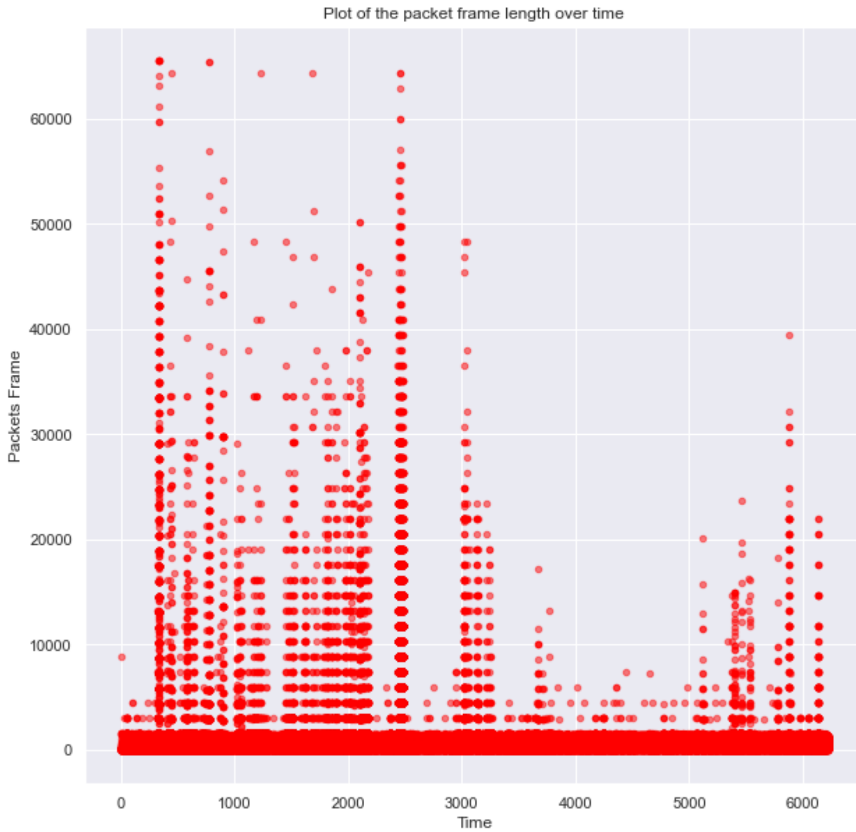


Figure 7: Visualization of the Packet Frame Overtime

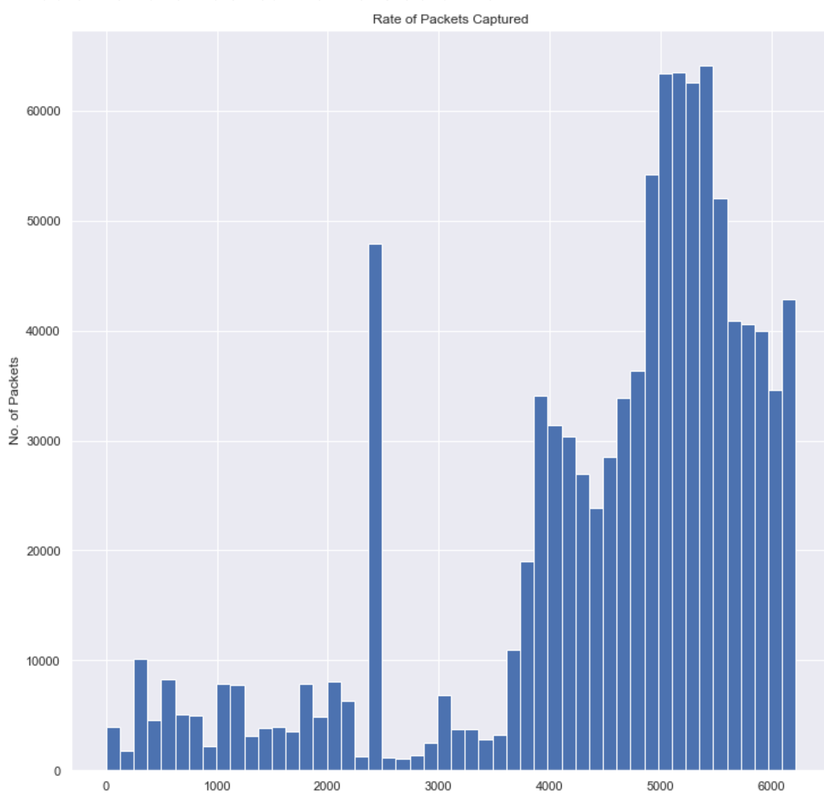


Figure 8: Histogram of the Packets Captured at different Rates

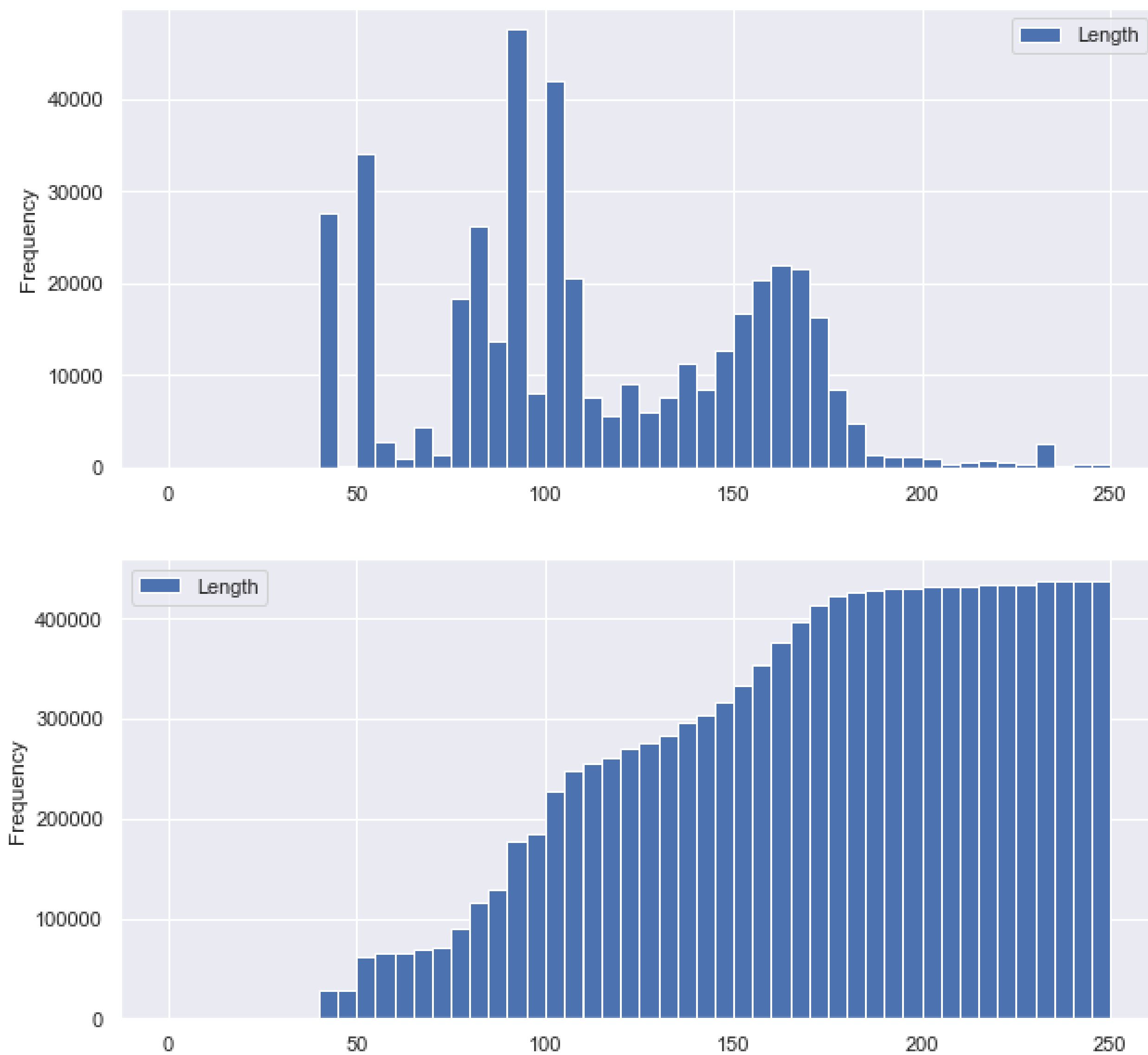


Figure 9: Visualization of the length of each Data Flow at different Frequency

Discussion and Future Work

Students realized that studying the Internet of Things platform is vital for electronic commerce as it facilitates the exchange of goods and saves time and energy. It is also used in some industries to monitor the number of goods produced, design and present products, advertisement, and management. Many industries use it as a means of securing their products and services. Banks use it to maintain their customer accounts, ledger, update electronic fund transfers, and process vast amounts of cheques, credit cards, and daily transactions.

Furthermore, government and enterprises use engineering knowledge to maintain citizens' databases, as a means of payments for government workers, for word processing of some government projects, for effective communication among different regions, countries to ensure the reinforcement of the law and government policies. Hence the importance of understanding the network data flow to make any essential decision. The next step includes students performing penetration tests and utilizing machine learning techniques to create algorithms that will train the collected data set to detect inconsistencies in data traffic and determine when the system is under attack.

Conclusion

This study explores an IoT Arm Pelion platform, paving the way for future studies. Students discovered that many customers are unaware that other parties are collecting their personal information. Users are only focused on the cloud provider's services and are unaware of the Internet of Things. Even while these devices provide many benefits to users, research has revealed that hackers exploit their weaknesses to obtain unauthorized access to the users' network. As a result, we require an increase in the number of people in cyberspace to resolve the issue posed by the Internet of Things devices. Our students developed a comprehensive understanding of networks and the value of teamwork while completing this project. Student involvement in this type of research is almost sure to secure employment after graduation. Students and teachers gained various engineering skills, such as team cooperation, presentation mastery, C and Python programming abilities, Internet of Things instruction, and cybersecurity principles.

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Appendix

Research Experience for Teacher (RET): Lessons Plan and Classroom Activities
After gaining an invaluable experience with IoT applications and platforms, the teacher developed lesson plans, hands-on activities, and projects to teach in the upcoming year. These activities and projects are intended to introduce STEM fields, especially engineering careers. The exercises and activities align with state core standards and the Standards for Technological Literacy (STEL). Table 3 presents the pedagogical technique to introduce the course to students.

Table 3: Unit 4 Introduction to Microcontrollers and Microprocessors for Engineering Education

Unit 4: Introduction to Microcontrollers and Microprocessors for Engineering Education	
Course	Digital Electronics - DE (11th Grade)
Lesson	Internet of Things - IoT
Basic Direct Teach Lesson (Includes Special Education Modifications/Accommodations)	
Instructional Objectives	Students will be able to: • Define Internet of things (IoT) • Demonstrate understanding of an IoT platform • Find how smart devices connect to the Internet • Research on the pros and cons of the Internet of things • Complete a project by researching and exploring different IoT applications. • Search for career opportunities related to the Internet of things
Rationale	After completing this lesson, students will explain the concept of IoT, IoT platforms, and applications. Students will then apply this knowledge to do a research project on an IoT platform.
Duration of Lesson	The lesson plan will take five weeks.
Word Wall/Key Vocabulary	IoT, Microcontroller, Microprocessor, IoT, Sensor, Protocols, Bluetooth, Network,
Materials/Specialized Equipment Needed	Hardware Materials: • Agora product development kit • Arduino Board • Wireless Temperature Sensor • Wireless soil humidity Sensor • SD cards use to flash the image into the board. Teaching Materials: • KWL Worksheet

<table>
<tr><td></td><td colspan="2">Engineering Notebook
Computer access
AWS IoT services</td></tr>
<tr><td>Getting Started
(May include pre-assessment for prior knowledge)</td><td colspan="2">ASK: Students are asked the following questions at the start.
What comes to their mind when they think about the Internet of Things? Record their responses on the KWL Worksheet. They will complete the first column and write down what they know about the Internet of Things.
Open Discussion:
Students will discuss their responses.
The teacher will briefly introduce the lesson.</td></tr>
<tr><td rowspan="2">Lesson and Activities</td><td>Outline</td><td>Instructor Notes</td></tr>
<tr><td>Lesson 1: Intro-What is IoT?
A. Play the introductory video
B. Presentation and discussions
<u>Student Activity 1:</u> KWL Column 2
C. After watching the video, students will continue working on the second column of the KWL chart
<u>Student Activity 2:</u> Debate Pros and Cons of IoT
<u>Student Activity 3:</u> Handout (Interactive all Connected IoT project)
EXTENDED LEARNING OPPORTUNITIES:
Research career opportunities associated with IoT. (Occupational Outlook Handbook - Search Computer and Information Technology Occupations to learn more).
Invite guest speakers from the field to the class to discuss IoT and IoT opportunities.</td><td>PPT presentation – What is IoT?
Introduction video- https://ed.ted.com/best_of_web/vypSL3VO
Schedule of Assignments
Objectives
Driving Questions
What is the Internet of Things?
The Technologies Behind IoT
IoT Past and Present: A Timeline
IoT the user Home and in the World
The Cost of Convenience: Pros and Cons of IoT
The Future of IoT and Career Opportunities
Vocabulary</td></tr>
</table>

	• Smart Building Technology: Architectural Design Activity	

	Lesson 2: Microcontrollers/Microprocessors
	Student Activity 1:
	• Creating Mbed account
	
	Student Activity 2:
	• Pin configurations - Nucleo Board
	
	Student Activity 3:
	(Handouts)
	• Using Mbed compiler to import codes
	    • Blinking LED light
	    • 'Hello world'
		• Video Presentation – Microprocessors)
		• Schedule of Assignments
		• Objectives
		    • Understanding pin configuration
		    • Basic coding using Python programming language
		    • Using online compiler
		• Driving Questions
		• Vocabulary

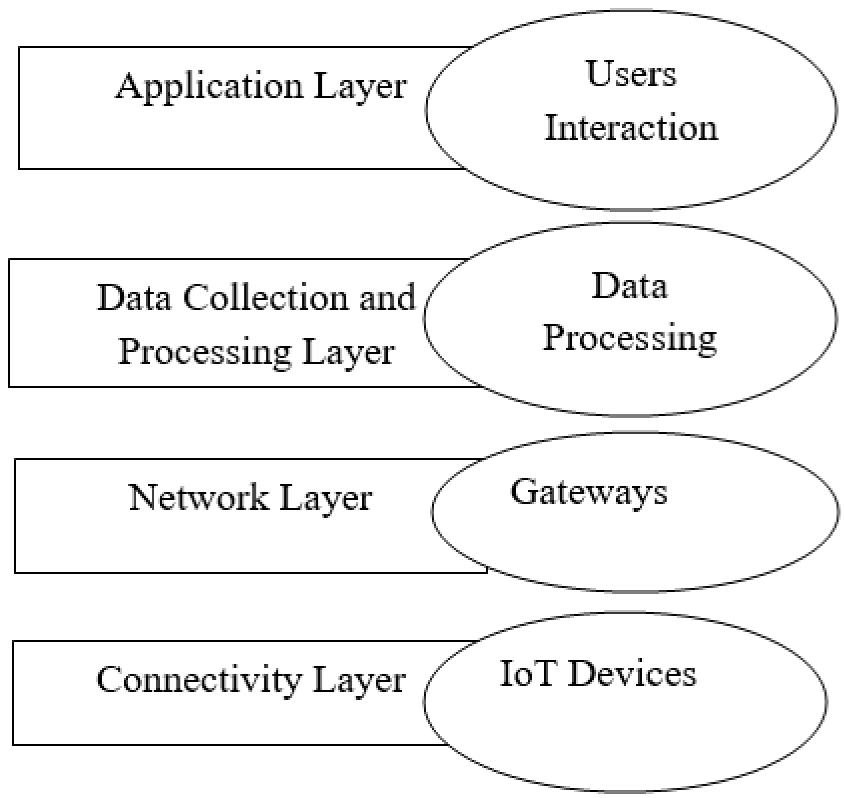
	Lesson 3: Project
	IoT Application in Agriculture
	(AWS IoT Services)
	
	Smart Garden Project: [Teams of 4s]
	• Set up the Smart Garden platform
	• Perform data visualization & analysis
	• Create a dashboard/Web application
	
	Student Activity 1:
	• Research, analysis, and present sensor devices
	    • Smart Temp sensor
		• PPT presentation
		    • Introduction video IoT in Agriculture
		    (2) IoT Based Smart Agriculture System ESP32 | Smart Gardening | MQTT Protocol | IoT Projects Ideas - YouTube
		    • Introduction to STMicroelectronics and Azure IoT - (2) STMicroelectronics Starter kits for Azure IoT - YouTube
		
		• Objectives: SWBAT.
		    • Set up the Smart Garden platform
		    • Perform data visualization & analysis
		    • Create a dashboard/Web application

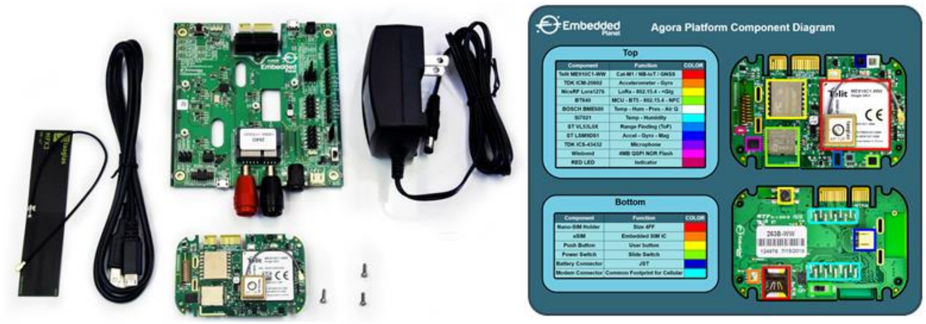
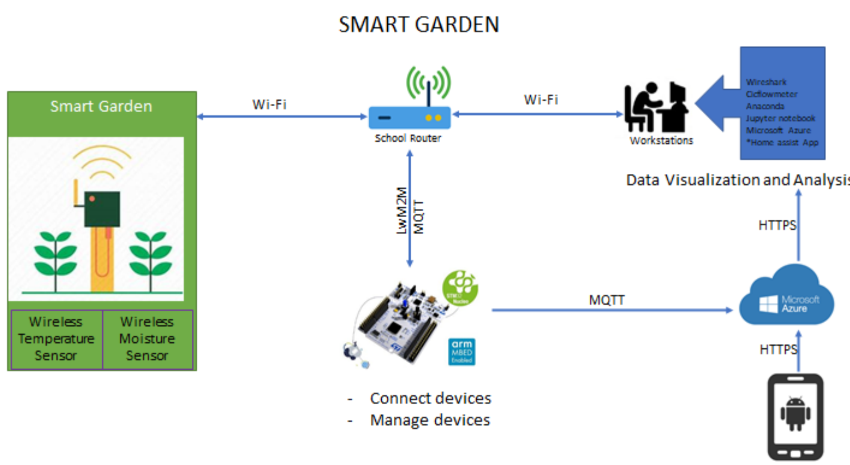
	• Smart Soil Moisture Sensor
	Student Activity 2:
	• Research, analysis, and present sensor devices
	Student Presentations
	• Students present their group presentations to the class
	• Questions to Consider
		• Materials
		    • Agora board
		    • Wireless Temperature Sensor
		    • Wireless Soil Moisture Sensor
		    • STMicroelectronics Starter kits for Azure IoT.
		• Vocabulary
		• Project Team Protocol, including team member roles

Guided Practice *	• Share the RET/REU project and experience with students • The teacher will observe student teams as they work on the IoT project and answer questions and provide feedback • Implement accommodation strategies for IEP/504 Plan students	
Lesson Closure	• Reflection • Evaluation	

Summative/End of Lesson Assessment	**Informal Assessment:**
	• Observation as students works on the project.
	    • Debating pros and cons of IoT
	    • Research Presentations
	    • Project - Smart IoT
	• Presentations
	Formal Assessment:
	• Assignments
	• Written Assessments
	• Project presentations	

References/Resources/ Teacher Preparation	Resources: 1. https://ed.ted.com/best_of_web/vypSL3VO - Intro video 2. https://www.vox.com/2015/1/15/11557782/a-beginners-guide-to-understanding-the-internet-of-things 3. https://os.mbed.com/built-with-mbed/ 4. https://www.iotforall.com/what-is-internet-of-things 5. https://os.mbed.com/teams/mbed-os-examples/code/mbed-os-example-pelion/ 6. Klika-Tech/nucleo-azure-iot-demo (github.com) 7. Klika-Tech/nucleo-azure-iot-demo (github.com)	
Recommended Strategies		
Reading Strategies	• Use graphic organizers - Use the spreadsheet provided by RET Mentor • Reread material • Visuals • Research guidance & resources	

Graphic Organizers/Handout	• KWL form • Provide charts and Architectural/Conceptual diagrams
Writing Strategies Journal Entries	Read and write frequently Offer various prewriting options Use guided Practice Revise together as a class
Other Essential Lesson Components	
Enrichment Activity (e.g., homework assignment)	• Homework assignments.
Lesson 1	**IoT Architecture** 

<table>
<tr><td>Lesson 2</td><td>Agora Development Board

</td></tr>
<tr><td>Lesson 3</td><td>SMART GARDEN

</td></tr>
</table>

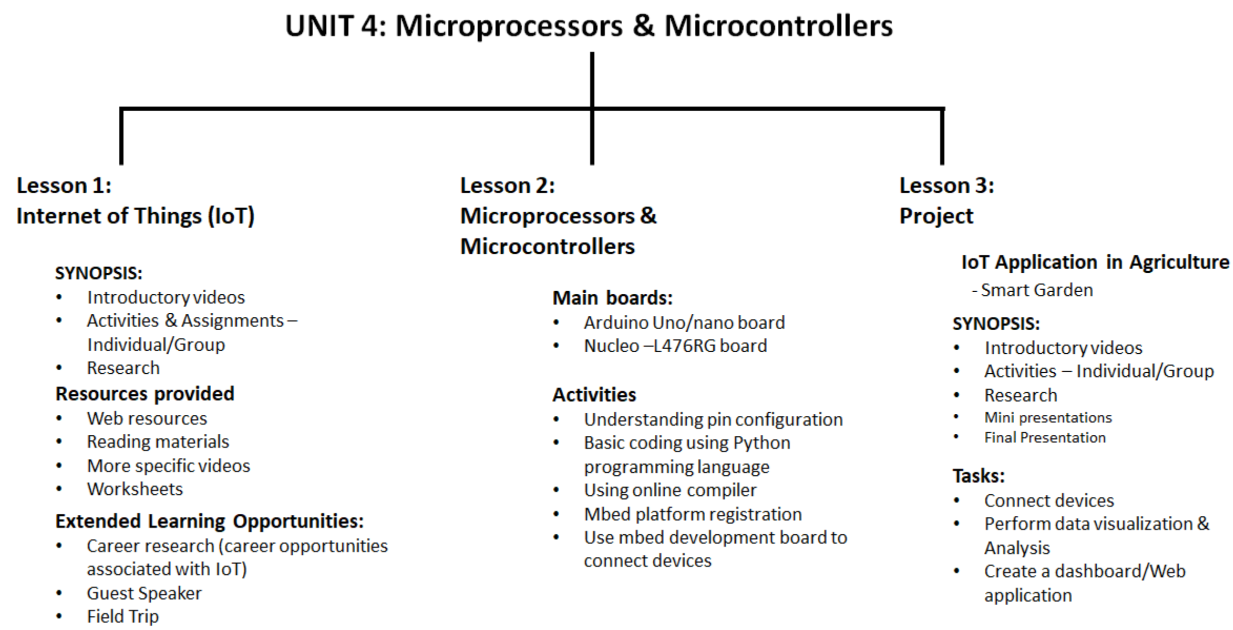


Figure 11: Diagram of the Lessons

We cover three lessons in the digital electronics course unit 4 entitled "Microprocessors and microcontrollers."

- Lesson 1: will introduce the concept of the Internet of Things (IoT). Students engage in activities and mini-research projects that enable them to explore this concept. Additionally, we invite guest speakers to talk to students about IoT security and career opportunities. Students also take field trips to enable them to explore and learn more about IoT.
- Lesson 2: Students will get introduced to microcontrollers and microprocessors. Students will use these microcontroller/microprocessors to learn basic coding using a python programming language.
- Lesson 3: IoT application in agriculture (Smart Garden). The idea here is to create a school garden where students can connect monitoring devices, perform data visualization and analysis, and create a dashboard that displays the readings from the garden devices.

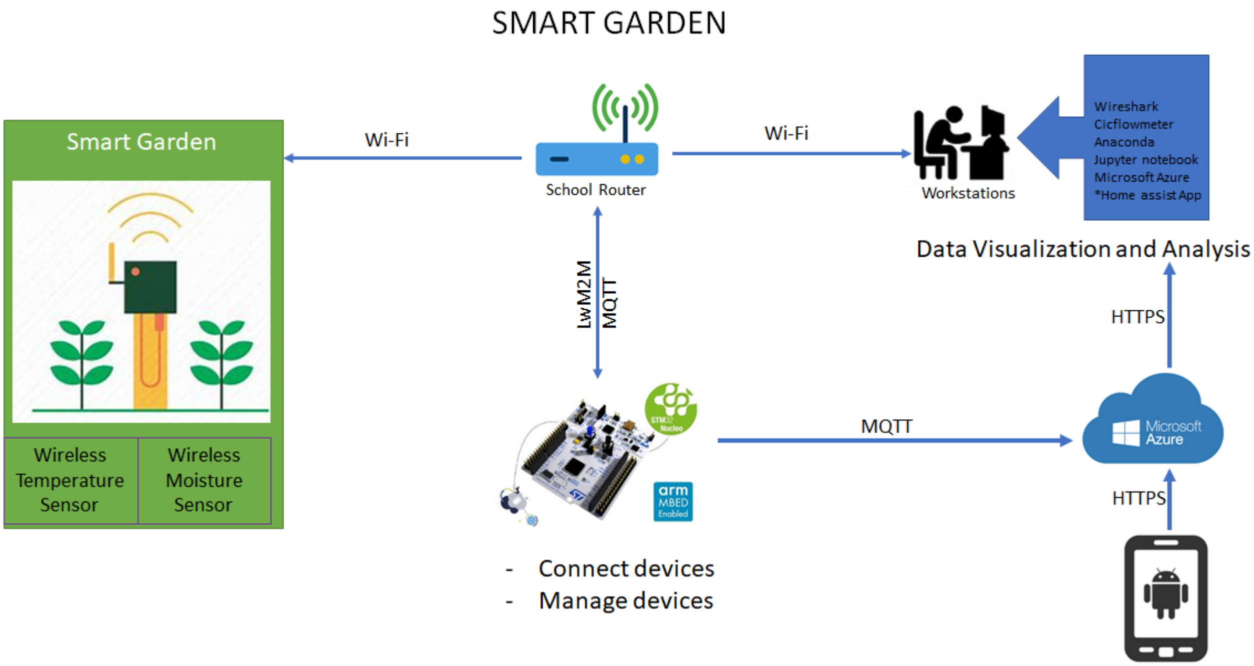


Figure 12: IoT Smart Garden Project Architecture

Materials

Hardware

- Temperature sensor
- Soil Moisture sensor
- Nucleo Board device
- Azure IoT Platform
- Wireshark
- Anaconda (Jupyter notebook)

The intelligent garden comprises a wireless temperature sensor and wireless moisture for remote monitoring.